Dark Matter Experiments

at the

Fermilab Center for Particle Astrophysics

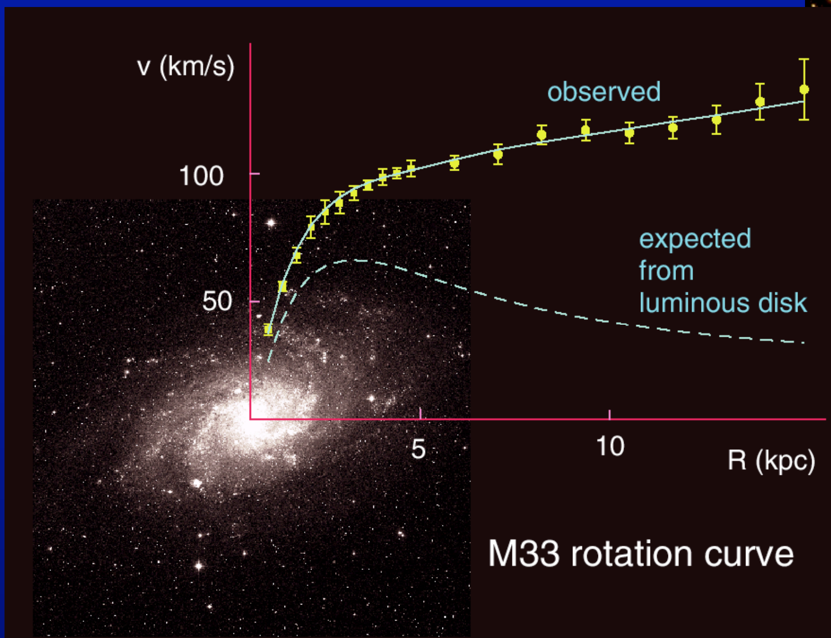
FCPA Retreat, April 2009

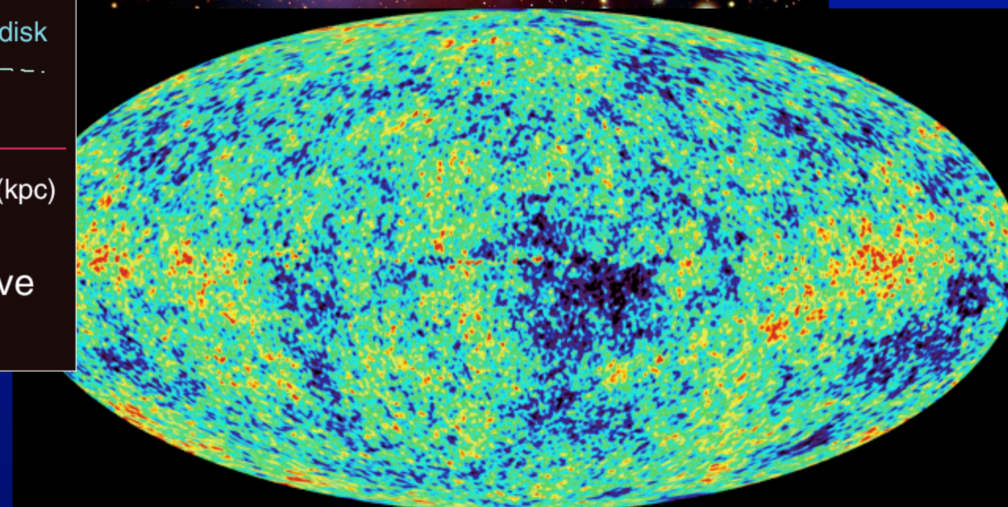
Emphasis

- Why do this project at Fermilab?
- What are the risks?
- What are the next steps?

- Direct Detection of Dark Matter
  - CDMS
  - COUPP

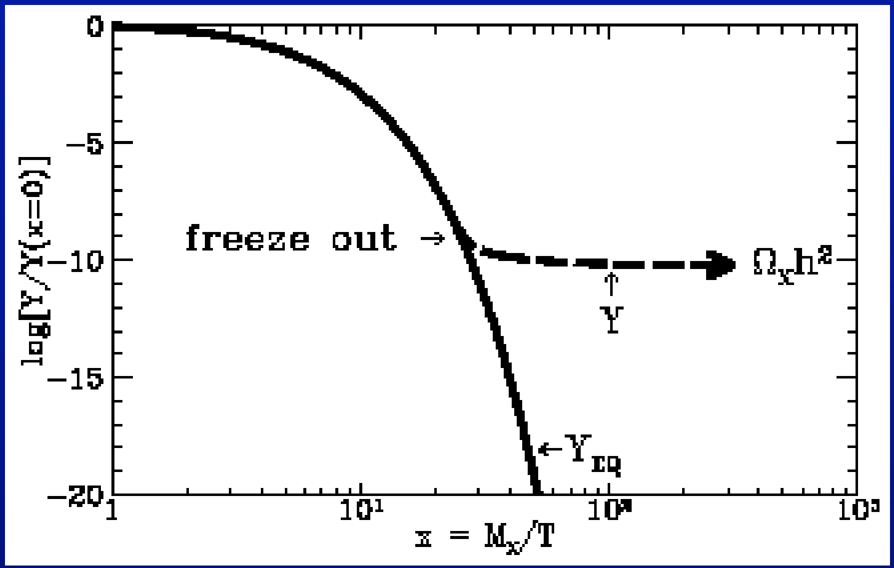
The Dark Matter Problem

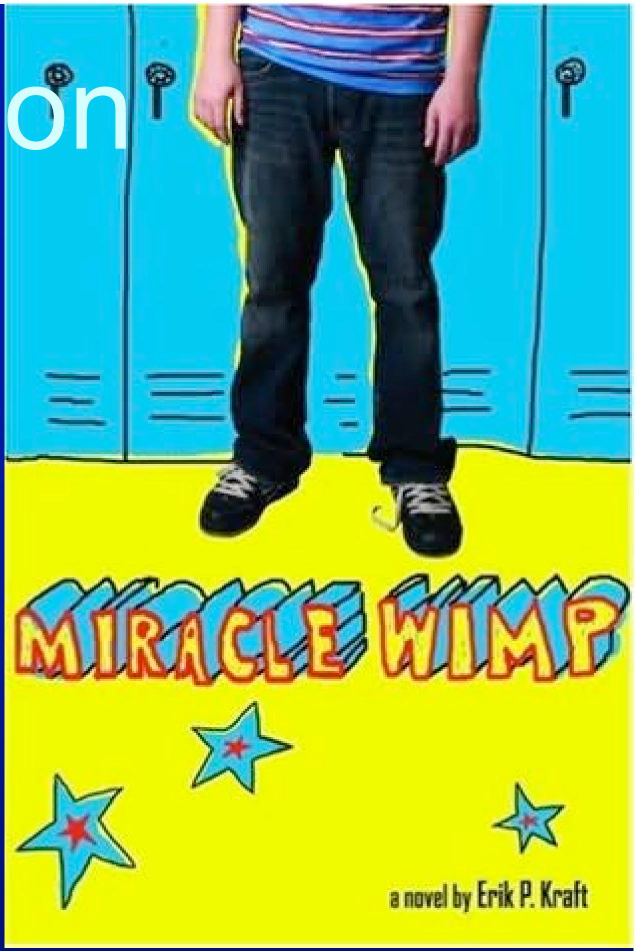




- Overwhelming evidence of the dark matter problem in astronomical observations
- One of the most rapidly growing fields of research in experimental particle physics

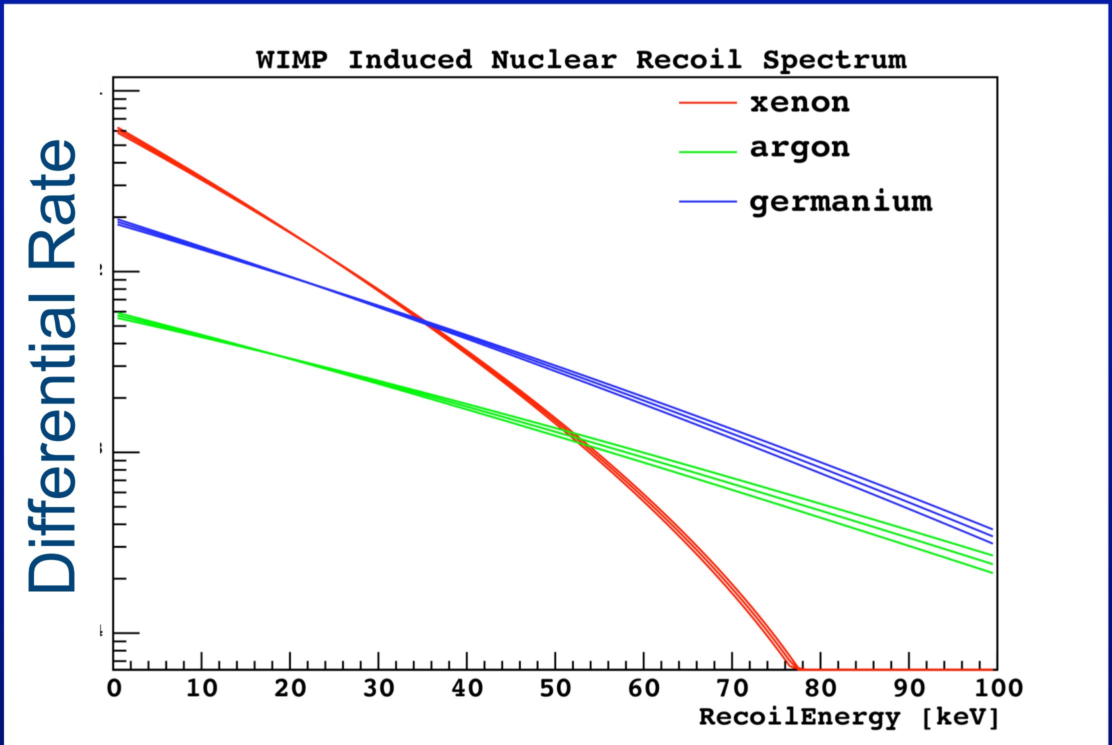
The Dark Matter Solution

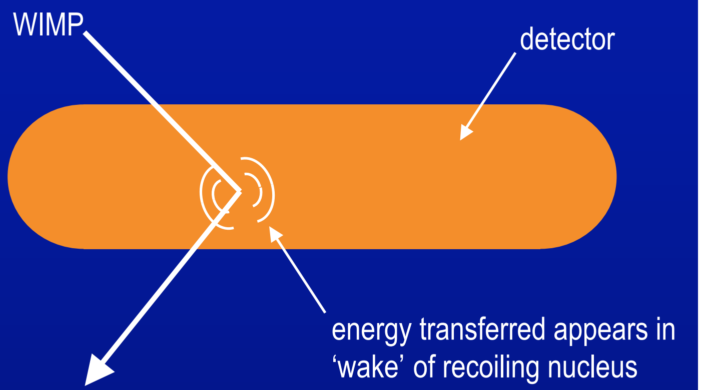




- ~1:4 luminous baryonic matter:non-baryonic dark matter is an attractive solution to the dark matter problem
- Weakly Interacting Massive Particles are the favored solution to the problem today
- The problem may even be with our understanding of gravity

Direct Detection of WIMPs





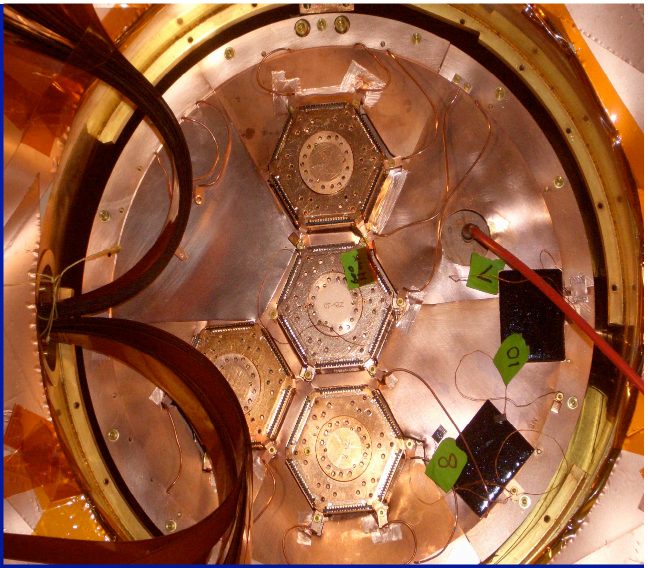
WIMP-Nucleus Scattering

- Rare event search (events per 10 kilogram years -> planning ahead for events per tonne year)
- Neutral elastic scattering, so focus on building massive, clean neutron detectors focusing on 1-100 keV nuclear recoils

A Center for WIMP Detection

- CDMS
  - Recent sensitive limits for spin-independent WIMP-nucleus elastic scattering
  - Recent axion limits
- COUPP
  - Recent sensitive limits for spin-dependent WIMP-nucleus elastic scattering at low WIMP mass
  - Rapidly increasing target mass and reducing backgrounds
- Infrastructure
  - Fermilab maintains two underground experimental areas: MINOS near hall and Soudan laboratory
- Research and Development
  - DAMIC, Depleted Argon TPC, Solid Xenon
  - See talks on Saturday for details

The Cryogenic Dark Matter Search



- CDMS is leading the field of direct detection of dark matter
- Based on cryogenic germanium and silicon crystals
- Latest results show the power of the technique for discovery

The CDMS Collaboration

Caltech
Z. Ahmed, **S. Golwala**, D. Moore, R.W. Ogburn

Case Western Reserve University
D. Akerib, C. Bailey, K. Clark, M. Danowski, M. Dragowsky, D. Grant, R. Hennings-Yeomans

Fermilab
D. Bauer, F. DeJongh, J. Hall, D. Holmgren, L. Hsu, E. Ramberg, R. Schmitt, J. Yoo

MIT
E. Figueroa-Feliciano, S. Hertel, S. Leman, K. McCarthy, P. Wikus

Queens University
W. Rau

Santa Clara University
B. Young

Stanford University
P.L. Brink, **B. Cabrera**, J. Cooley, L. Novak, M. Pyle, A. Tomada, S. Yellin

Syracuse University
M.Kiveni, M. Kos, **R. Schnee**

University of California, Berkeley
M. Daal, J. Filippini, N. Mirabolfathi, **B. Sadoulet**, D. Seitz, B. Serfass, K. Sundqvist

University of California, Santa Barbara
R. Bunker, D. Caldwell, R. Mahapatra, **H. Nelson**, J. Sander

University of Colorado, Denver
B. Hines, **M. Huber**

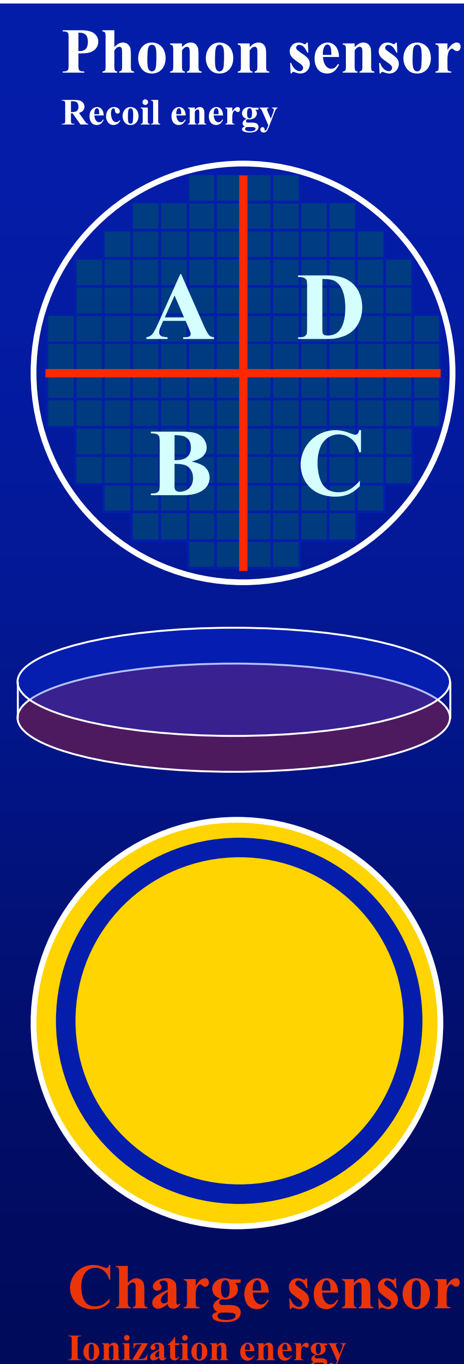
University of Florida
A. Achelashvili, D. Balakishiyeva, **T. Saab**, G. Sardane

University of Minnesota
J. Beaty, **P. Cushman**, L. Duong, M. Fritts, O. Kamaev, **V. Mandic**, X. Qiu, A. Reisetter

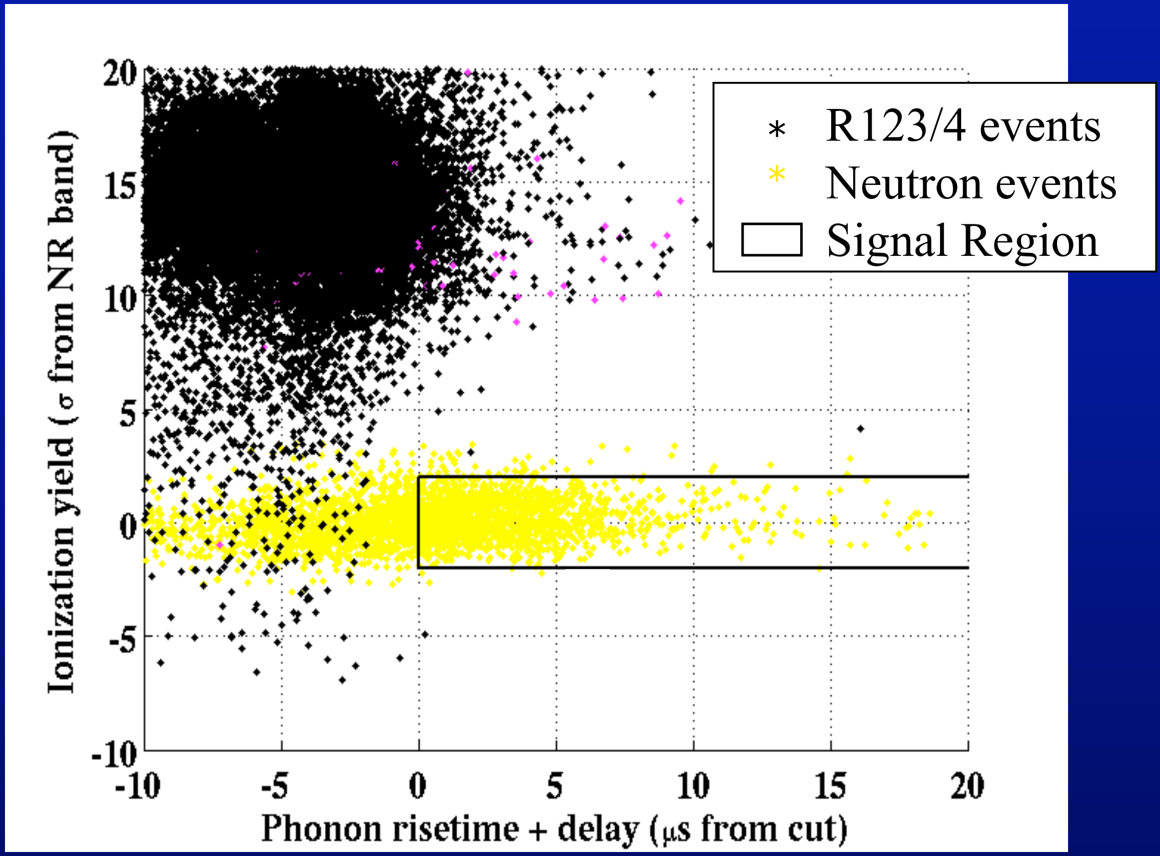
University of Zurich
S. Arrenberg, T. Bruch, **L. Baudis**, M. Tarka

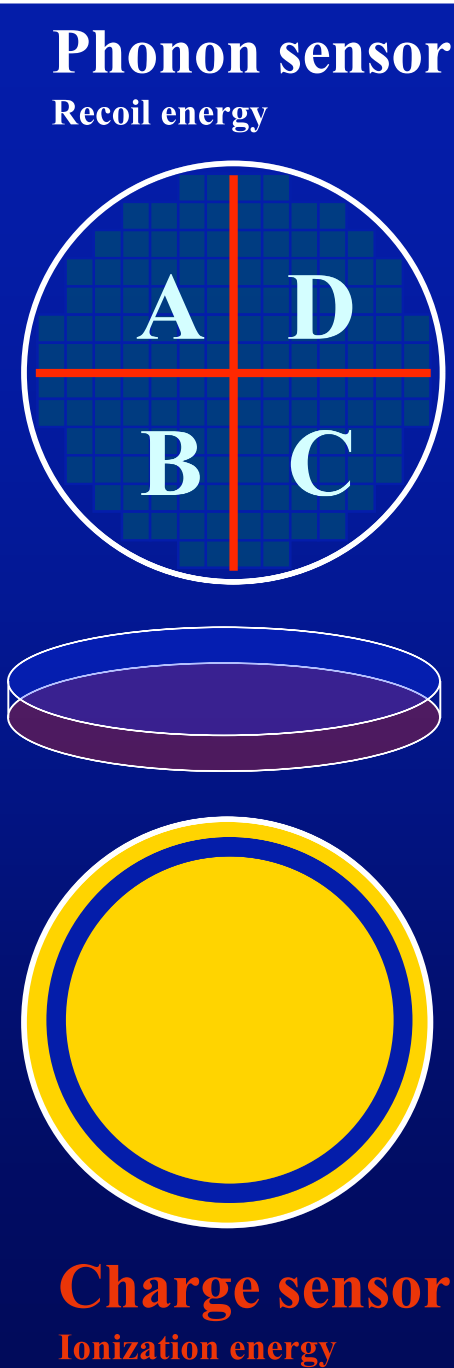
The CDMS Technology

- Measure energy deposited in the form of liberated charge carriers in silicon and germanium semiconductors
- Measure the total energy deposited bolometrically
- Use high bandwidth phonon sensors to identify events with poor ionization collection



The CDMS Technology





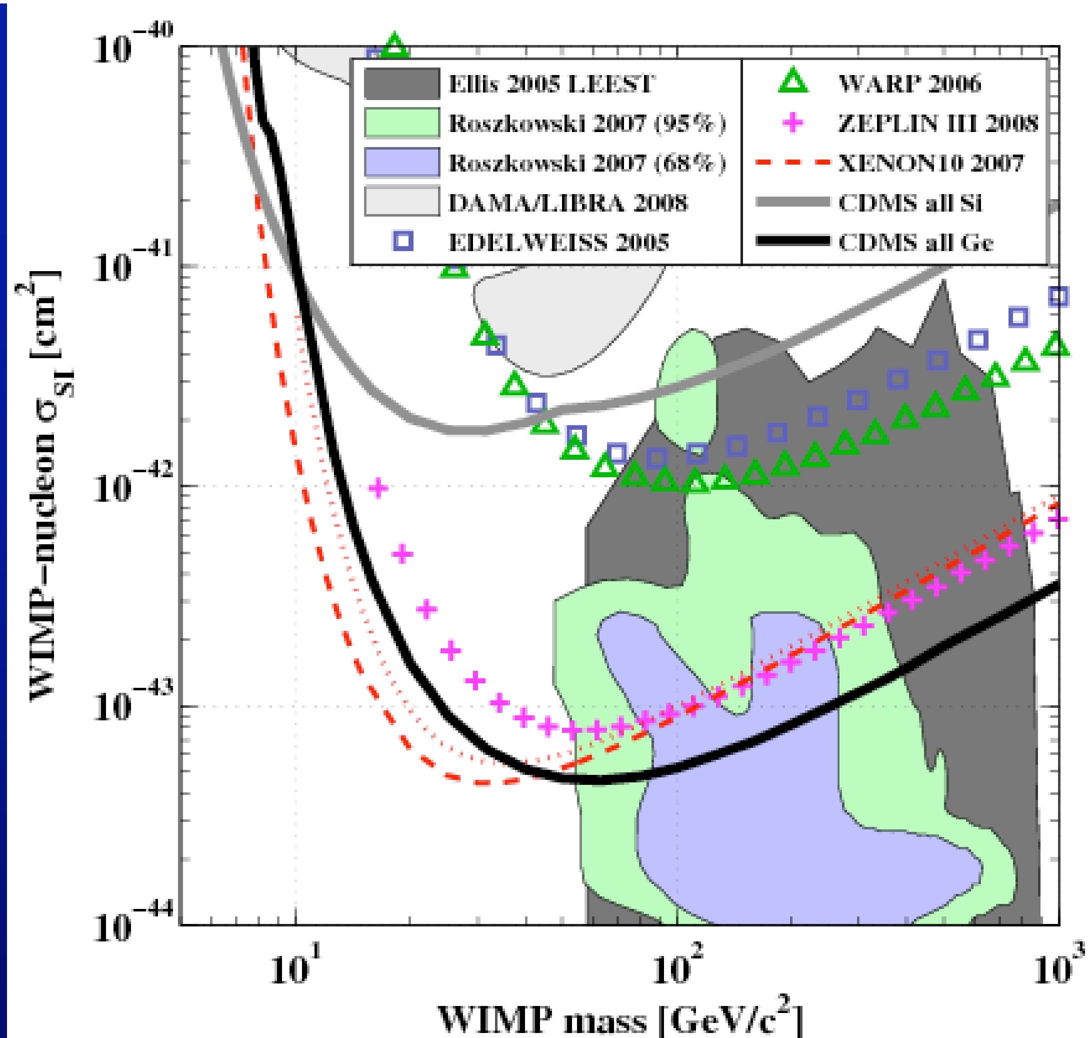
- Excellent background rejection and shielding lead to zero candidate events in latest data

Fermilab Involvement in CDMS

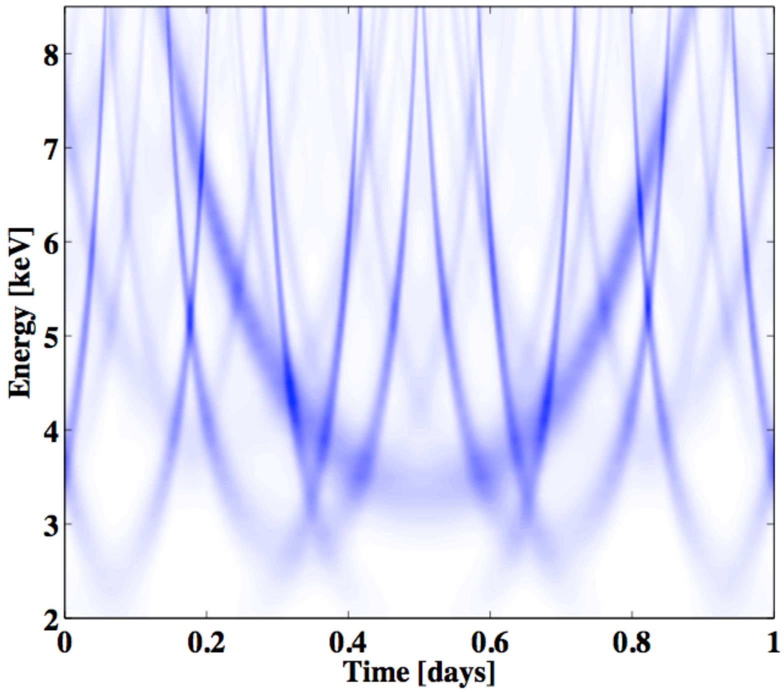
- Heavily involved in almost every aspect of CDMS
  - Soudan laboratory and operations
  - Project management
  - Data storage and analysis
  - Mechanical and electrical engineering
- Only detector fabrication and testing are not done at Fermilab
  - Fabrication at Stanford
  - UC Berkeley leads testing group that includes UFlorida and Queens University

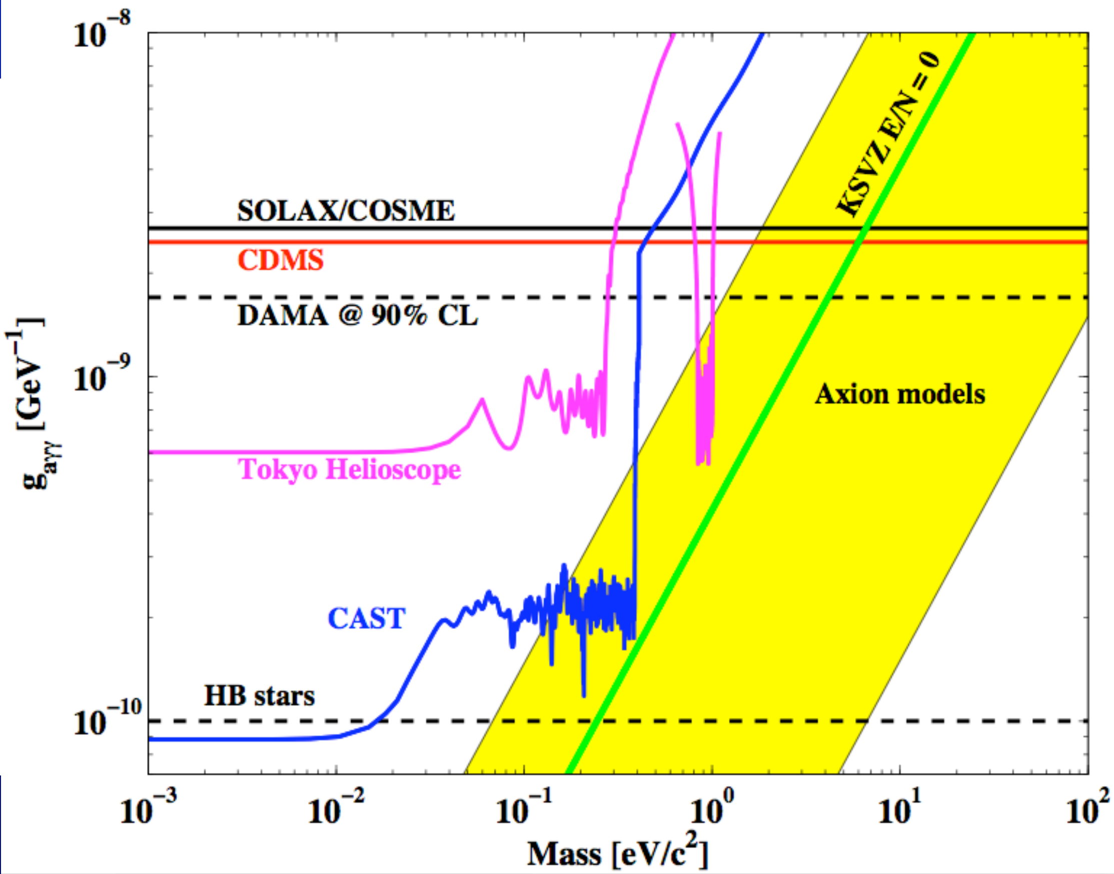
Latest CDMS Results

- The leading limit on spin independent WIMP-nucleus elastic scattering cross-section
- PRL **102**:011301 (2009)
- Only competitive background free result demonstrating the discovery power of CDMS



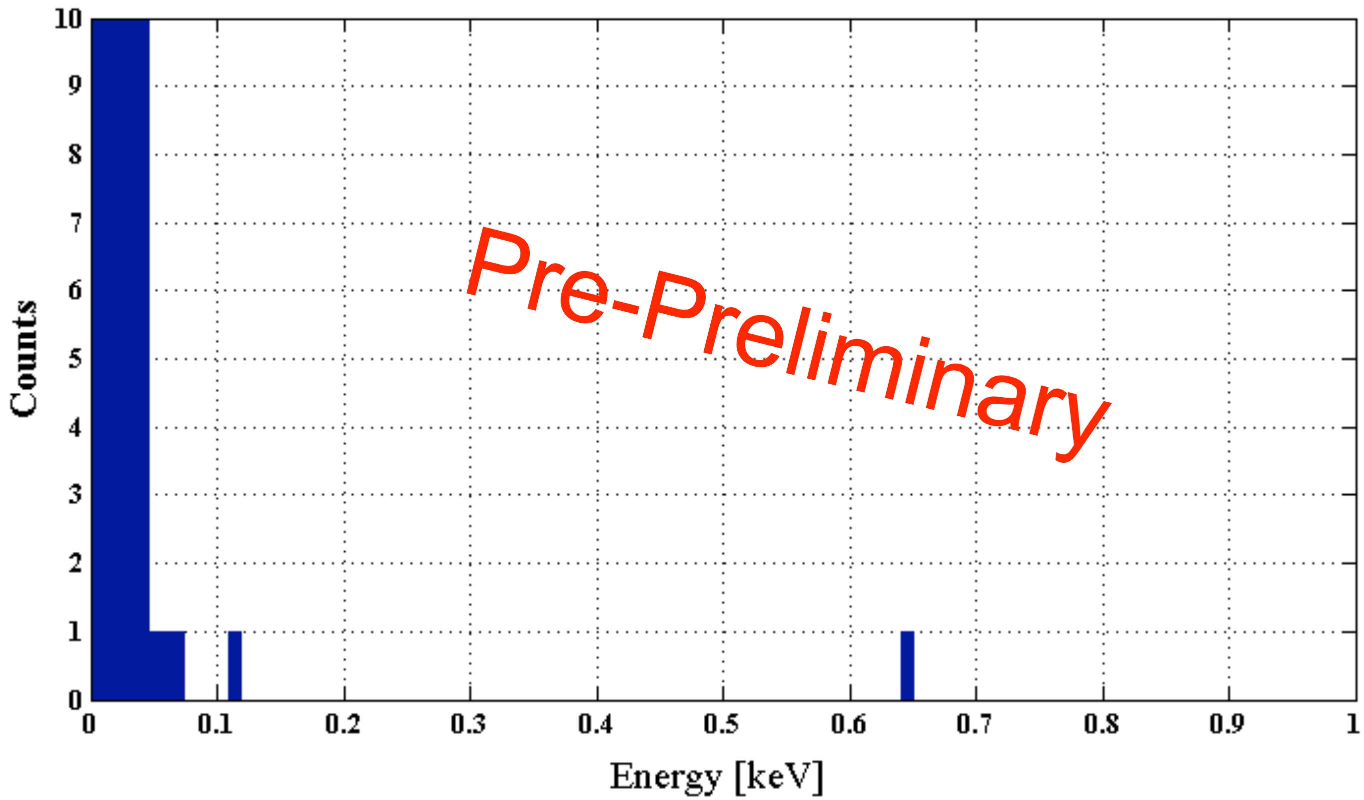
CDMS Solar Axion Search





- Search for Solar axions in referee process (arXiv:0902.4693)

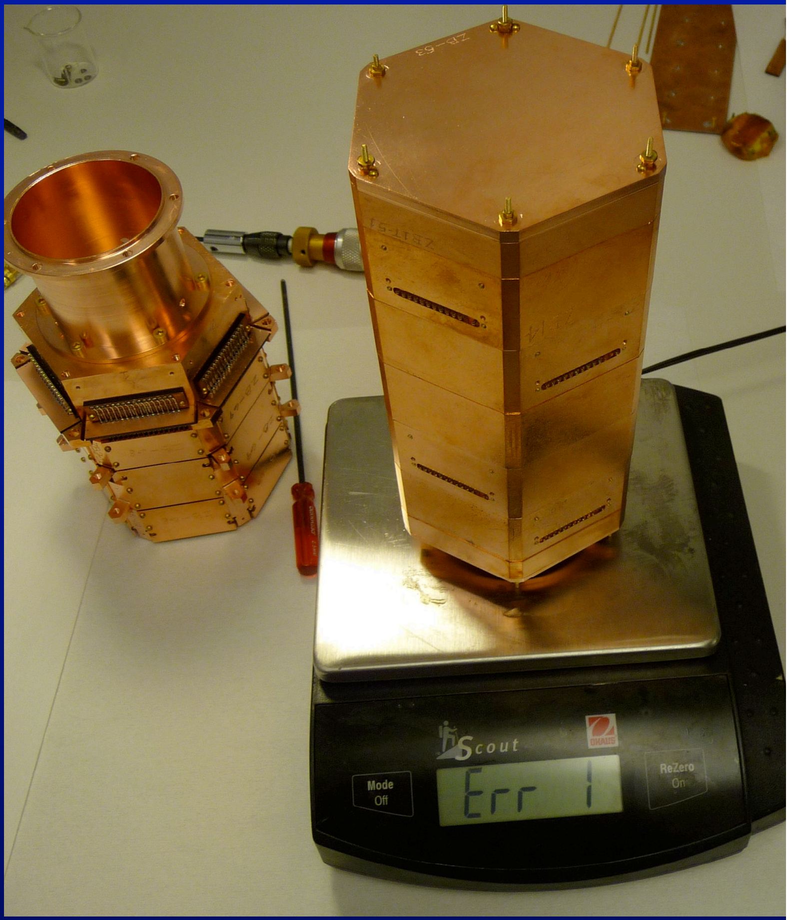
CDMS Low Threshold



- Standard running with 0.5 keV threshold under analysis
- Dedicated run with 0.05 keV threshold under analysis
- Neutrino detection possibilities

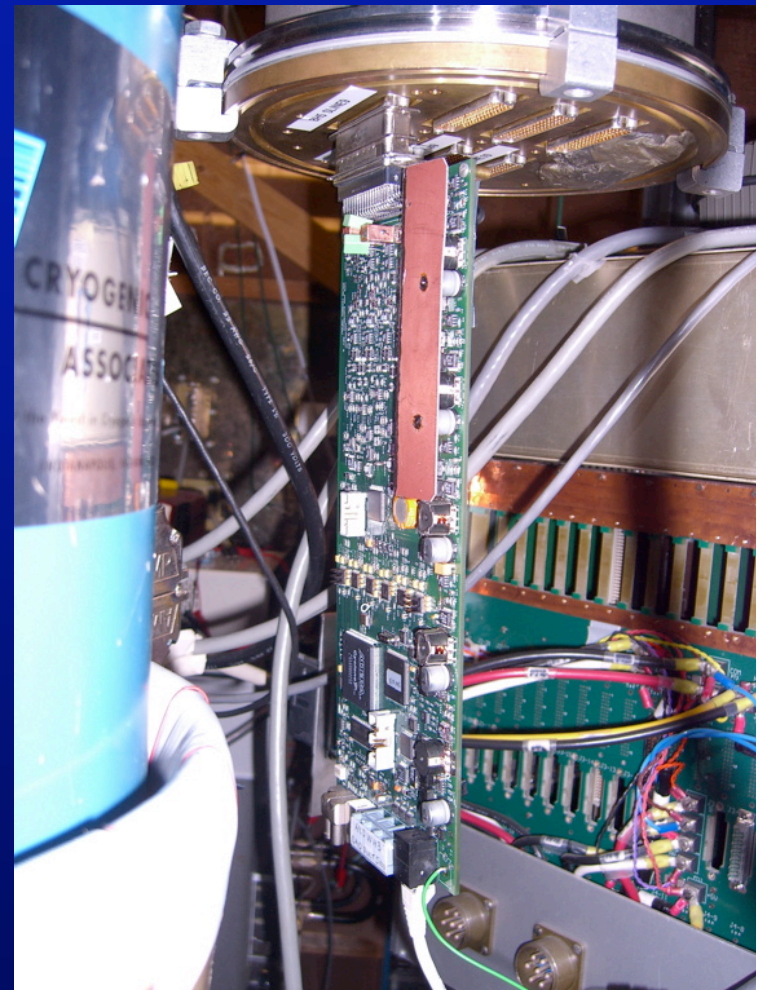
SuperCDMS

- New detectors are being installed (this week) in Soudan cryostat
- Detectors are 2.5 times larger (625 grams each)
- Detector fabrication output has increased (political situation is critical path item)



SuperCDMS

- Electronics have been modernized
- Order of magnitude reduction in cost
- Minimization of cables and connectors
- Enabling test facilities at University of Florida and Queens University



SuperCDMS Risks

- Perception that scaling CDMS technology to larger masses is more difficult than other competitive technologies (liquid detectors)
- Backgrounds will soon become unmanageable
  – Surface events
  – Neutrons (radiogenic and cosmogenic)

Chicagoland Observatory for Underground Particle Physics

- The return of the bubble chamber
- Latest results are competitive in spin-dependent parameter space
- New devices will answer key technical questions

The COUPP Collaboration

THE UNIVERSITY OF CHICAGO

Principal Investigator:
Juan Collar
(spokesperson)

Graduate Students:
Nathan Riley
Matthew Szydagis

Undergraduates:
Luke Goetzke
Hannes Schimmelpfennig

KICP Fellows:
Brian Odom

Fermilab

Wilson Fellows:
Andrew Sonnenschein

Staff Scientists:
Peter Cooper
Mike Crisler
Martin Hu
Erik Ramberg
Bob Tschirhart

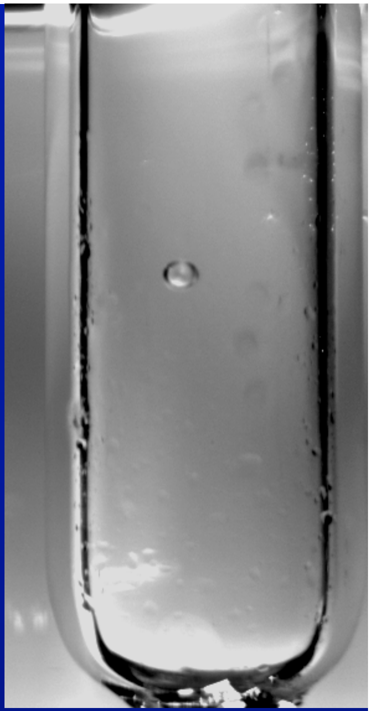
Principal Investigator:
Ilan Levine

Undergraduates:
Earl Neeley
Tina Marie Shepherd

Engineers:
Ed Behnke

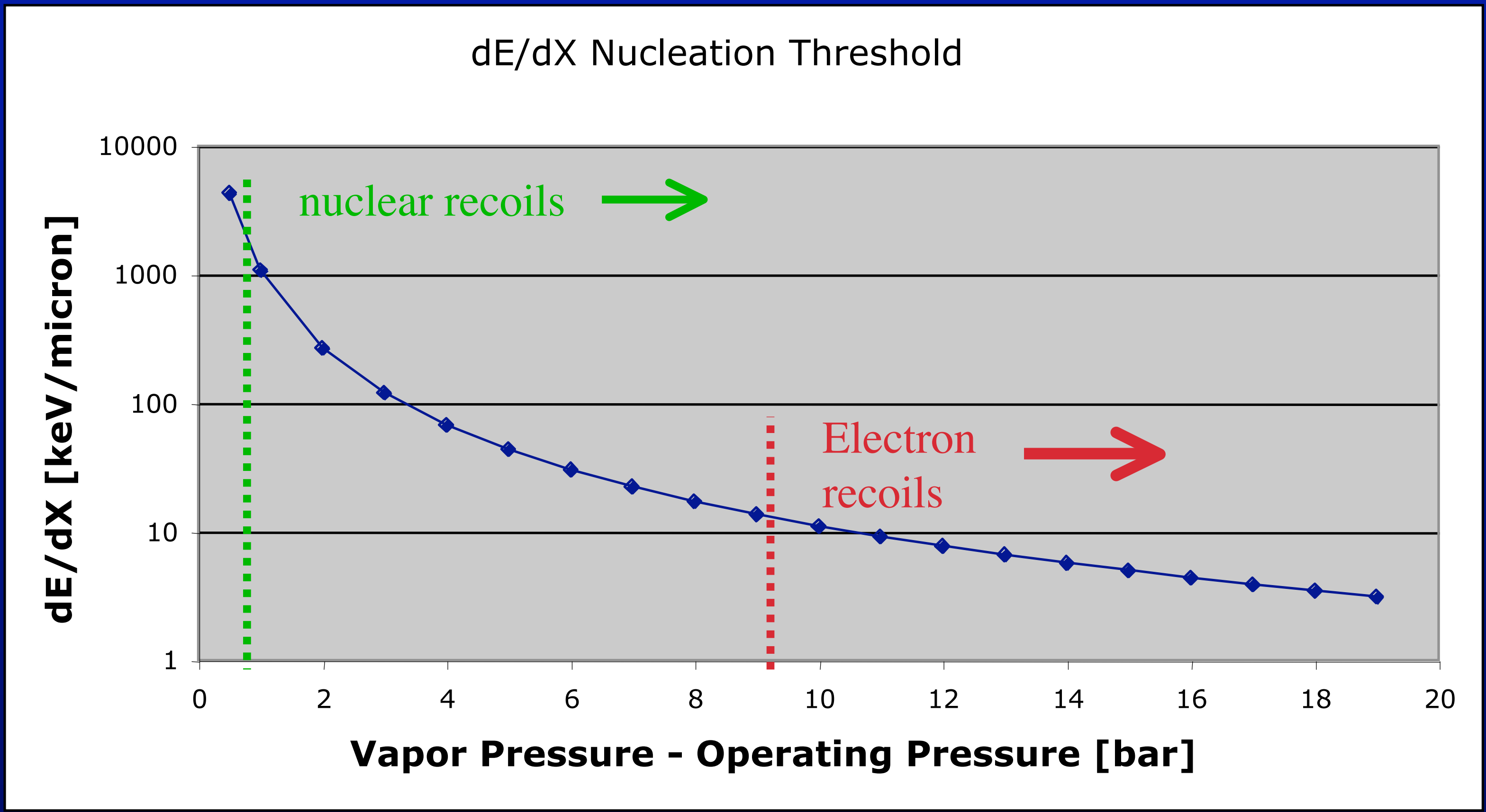
National Science Foundation
Kavli Institute for Cosmological Physics
Department of Energy

COUPP Technology



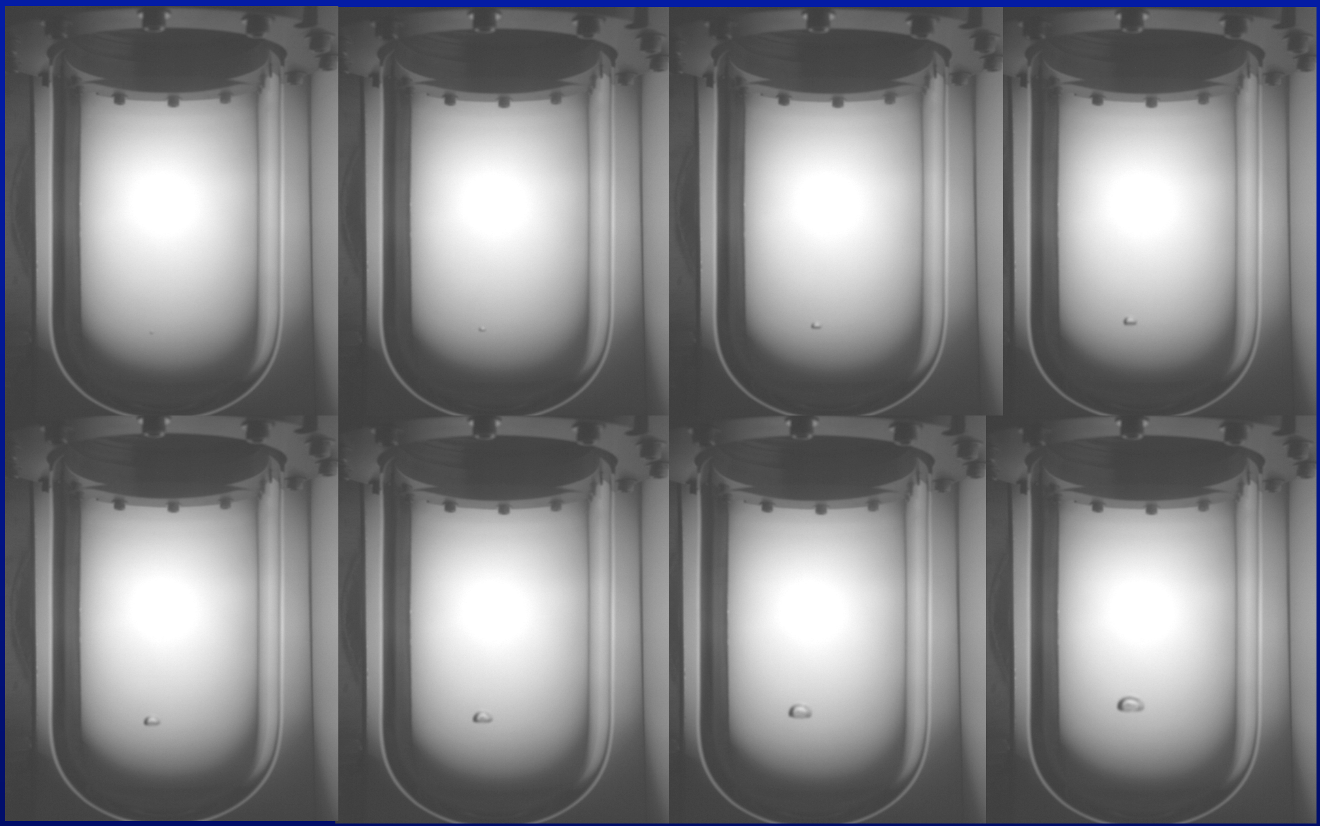
1. **Large target masses may be possible.**
   - Multi ton chambers were built in the 50's- 80's.
2. **An exciting menu of available target nuclei.**
   - Most common: Hydrogen, Propane
   - But also "Heavy Liquids": Xe, Ne, CF_3Br, CH_3I, and CCl_2F_2.
   - Good targets for both spin- dependent and spin-independent scattering.
   - Possible to "swap" liquids to check suspicious signals.
3. **Low energy thresholds are easily obtained for nuclear recoils.**
   - $<$ 10 keV easy to achieve according to standard nucleation theory.
4. **<u>Backgrounds due to environmental gamma and beta activity can be suppressed by running at low pressure.</u>**

COUPP Technology



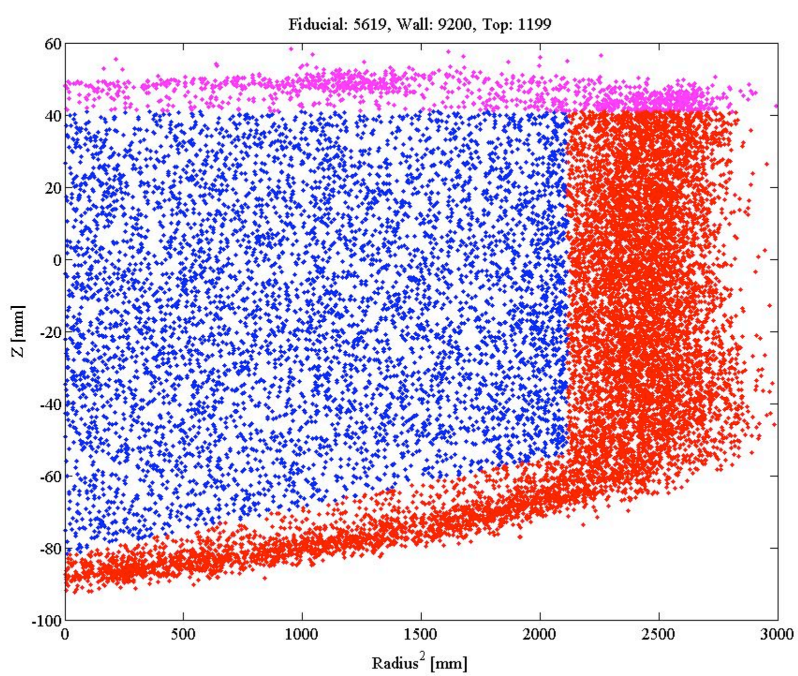
- dE/dX difference between nuclear and electronic recoils
- a low pressure chamber is insensitive to electron recoils

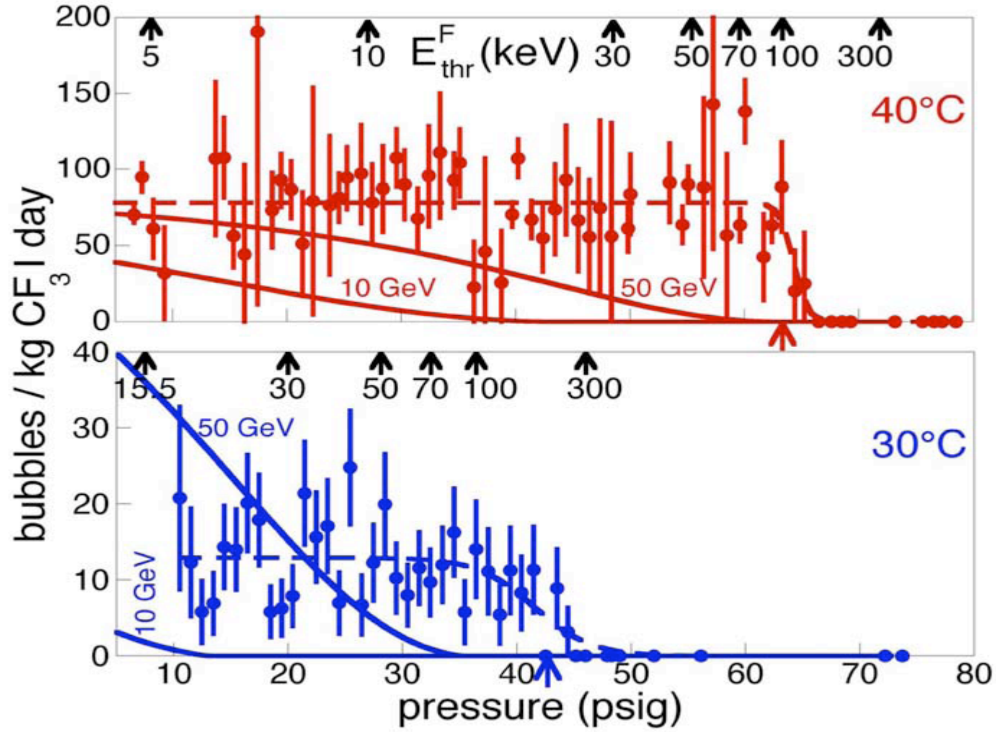
COUPP Technology



- High speed cameras monitor for single bubbles

COUPP Results - 2006 Run

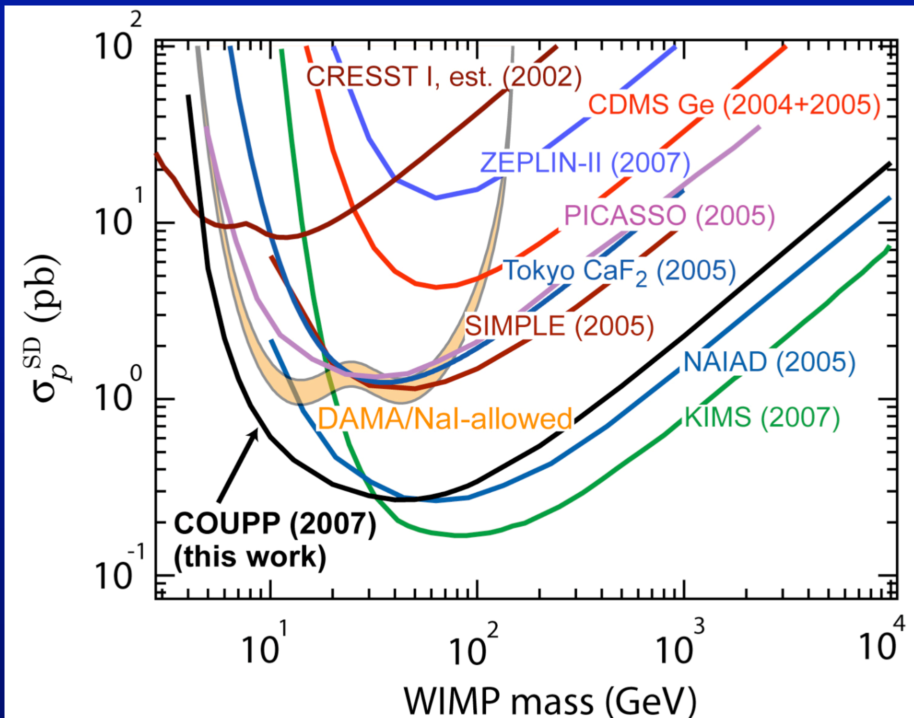




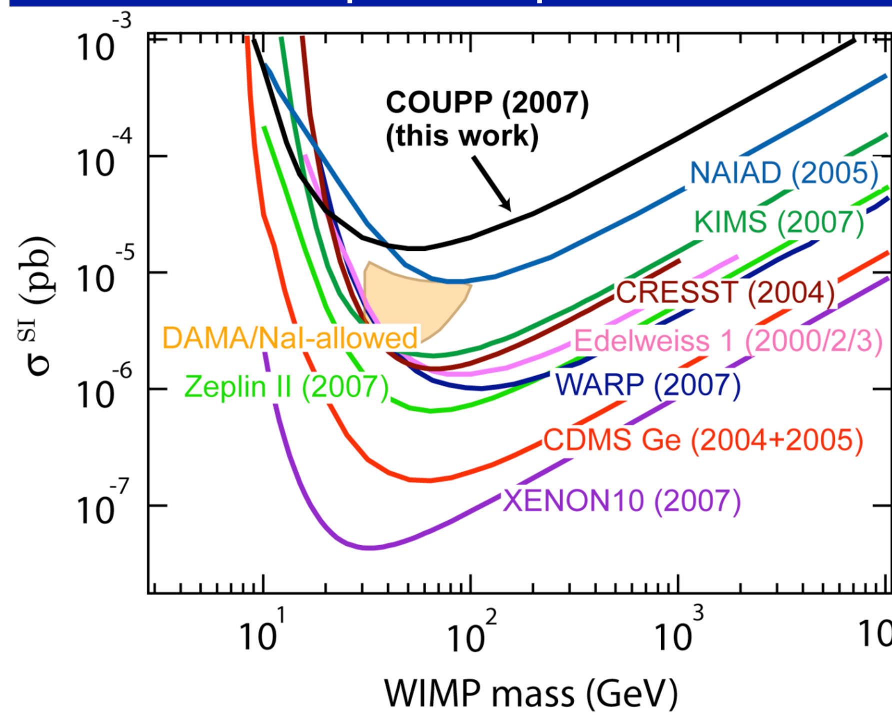
- Scan over pressures (thresholds) to create a integral spectrum
- Alphas have large dE/dX and pose a background issue

COUPP Results - 2006 Run

Spin-dependent



Spin-independent



- Science **319**, 933-936 (2008)
- Competitive spin-dependent limits due to Flourine target

Fermilab Involvement in COUPP

- MINOS near hall provides convenient shielding from cosmic radiation
- Accelerator Division has developed superb cleaning facilities for SCRF that enable increasing COUPP sensitivity
- Scientific and engineering expertise with bubble chambers is increasingly rare, but common at Fermilab
- As project organically grows, management expertise at Fermilab will become more important

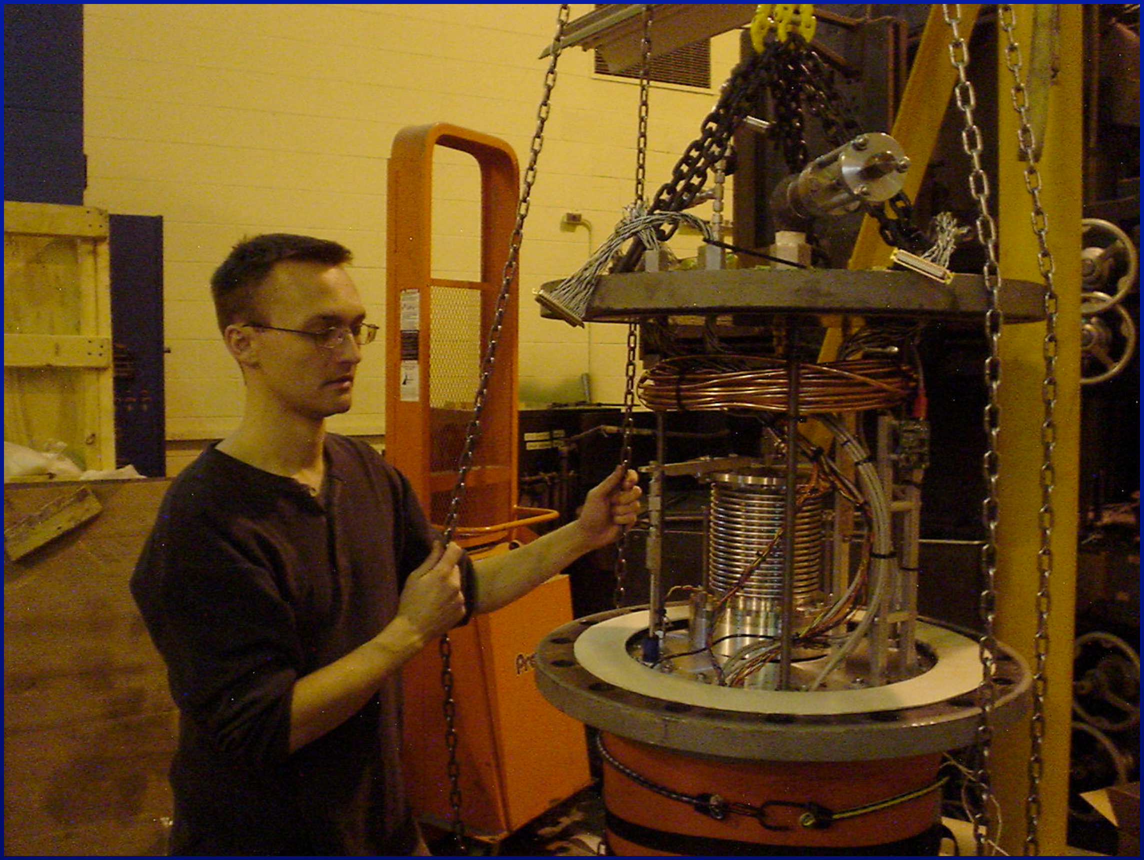
The COUPP continues

- Increasing target mass to 60 kg
- Upgrading 2 kg device with larger synthetic silica jar to demonstrate reduction in surface events

COUPP 60 Kilogram Chamber

- Moved to DZero yesterday
- Engineering run at DZero will proceed in the next months only missing water purification and CF_3I handling systems
- Plans to move underground are in discussion

COUPP 20 kg Chamber



- Now producing data
- Surface event rate is promising

COUPP
1 Liter Revisited

- Upgraded inner vessel now holds 4 kg target liquid
- Surface events impose deadtime limitation (30 s per event)
- 1 Liter inner glass vessel being replaced by a synthetic silica vessel

COUPP Risks

- Competitive spin-dependent sensitivity requires ~10^3 reduction in backgrounds
- Total event rate (surface events) is constrained by dead time
- Proliferation of bubble chambers is spreading the collaboration

Conclusions

- Fermilab is a world leader in direct detection of dark matter
- World class experiments (CDMS, COUPP)
- World class facilities (Fermilab engineering, MINOS near hall, Soudan laboratory)
- World class R&D (DAMIC, Solid Xenon, Dual-phase Argon TPC)